Observation of Astronomical Transients with the 1.5-m Kanata telescope

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on behalf of the Kanata team

Contents

- Introduction to the “Kanata” project
- Examples of Kanata observations
- New modeling technique

Astronomical transients

GRB

- ✓ Relativistic jets
- ✓ Long GRB: core-collapse SN
- ✓ Short GRB: neutron star merger?
- ✓ Prompt emission (gamma-ray)
- ✓ Afterglow (all wavelength: Power-law decay)

Supernova

- ✓ Type Ia: thermonuclear explosion of white dwarfs
- ✓ Standard candle in cosmology
- ✓ Others: core-collapse of massive stars
- ✓ Hypernovae --- GRB connection

Nova

- ✓ Thermo nuclear runaway on the white dwarf surface
- ✓ Cataclysmic variable
- ✓ Recurrent explosion
- ✓ Power-law decay
- ✓ Progenitor of Type Ia SN ?

Dwarf nova

- ✓ Thermal instability of accretion disks
- ✓ Cataclysmic variable
- ✓ Natural laboratory of accretion disks
- ✓ Exponential decay

AGN

- ✓ Accretion disk + jet
- ✓ Blazars: jet directing to the line of sight
- ✓ Erratic variations in all wavelength from radio to gamma-rays
- ✓ Wide range of variation time-scale from a few minutes to a few decades.

X-ray transient

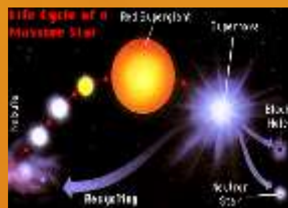
- ✓ Thermal instability of accretion disks
- ✓ The same mechanism of dwarf novae
- ✓ Microquasars: X-ray transients with jets
- ✓ Exponential decay with jet ejections

Different mechanisms for different groups → different research field

Concept of the "Kanata" project

GRB

Supernova



Nova

Dwarf nova

AGN

X-ray transient

"Generalist" telescope for transients

Quick response & Flexible operation

Unique instruments

Kanata telescope

- Telescope
  - 1.5m Ritchey-Chretien
  - F/12.2 f=18,300mm
  - FOV: 15 arcmin
- Instruments
  - HOWPol
    - Optical imaging, spectroscopy, & polarimetry
  - HONIR
    - Simultaneous optical and NIR
    - Under development
  - High speed camera and spectrograph
    - Optical imaging & spectroscopy
    - Time-resolution > 0.03 sec

Polarization of GRB afterglows

- GRB 091208B
  - Uehara+12, ApJL, 752, L6
- High polarization degree (~10%) in the early afterglow
- The mechanism for the amplification of ***B*** in shocks.
  - Plasma (Weibel) instability, predicting a low polarization
  - But, the observed PD was high, = 10%
  - MHD (Richtmyer-Meshkov) instability: triggered by the shock passing through non-uniform interstellar matter
- Unique instrument

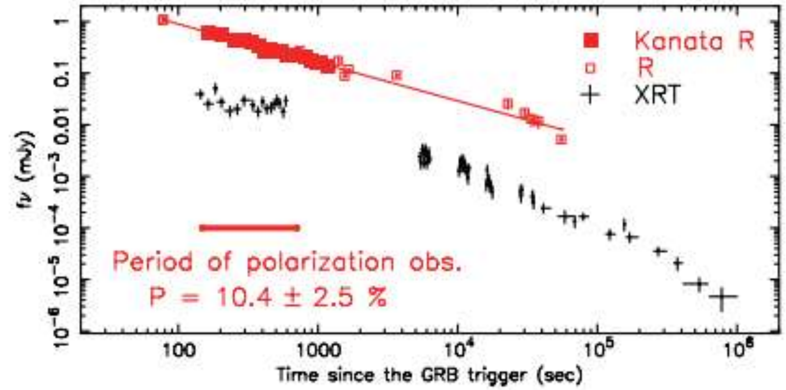


Figure 2. Optical and X-ray light curves of GRB 091208B. Our optical and *Swift*/XRT data are indicated by the filled squares and crosses, respectively. Open squares are the optical data reported in GCN. The solid lines are the best-fitted power-law models for the optical light curve (with the decay index of $\alpha_O = -0.75 \pm 0.02$). The thick horizontal bar at the left bottom part shows the period of our polarimetry. The derived polarization degree is also indicated.

(A color version of this figure is available in the online journal.)

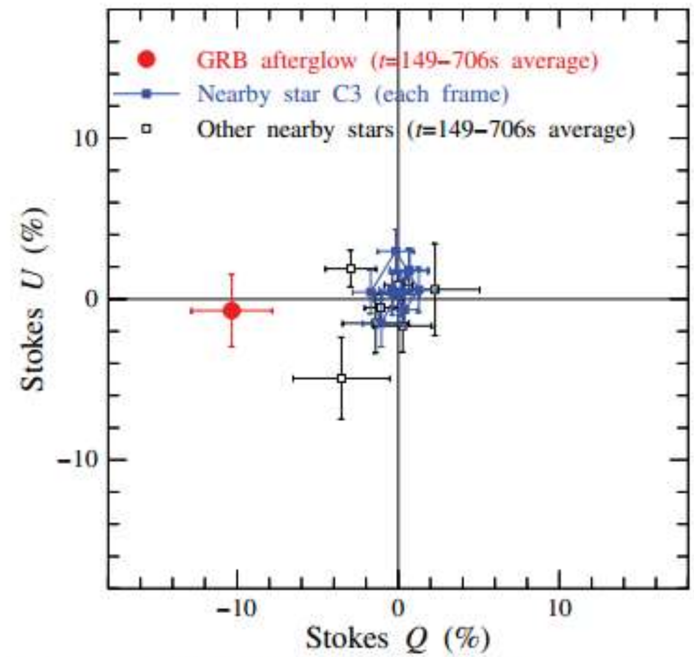
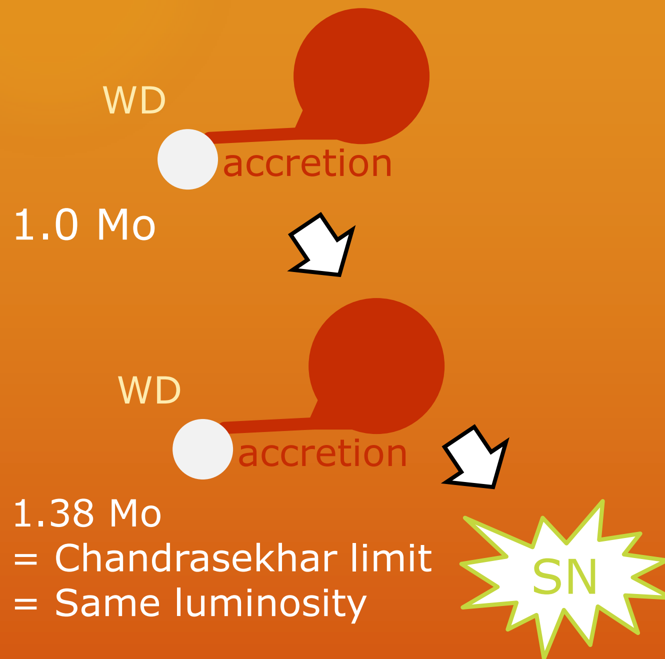
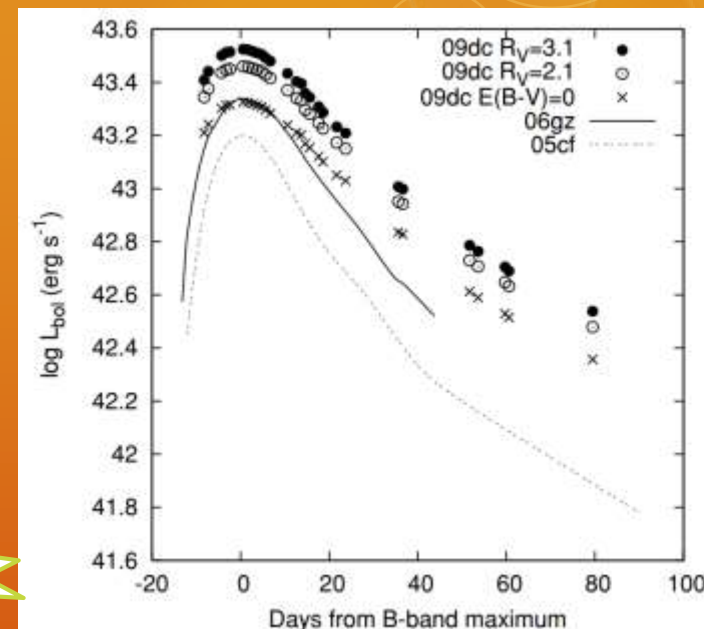


Figure 3. *QU* diagram of the GRB afterglow and nearby stars. For the bright comparison star C3, we demonstrate the frame-to-frame variation of *Q* and *U*, which suggests that the residual systematic is negligible ($\lesssim 1\%$). For other stars we show time-averaged polarization at t = 149–706 s.

Super-Chandrasekhar supernova

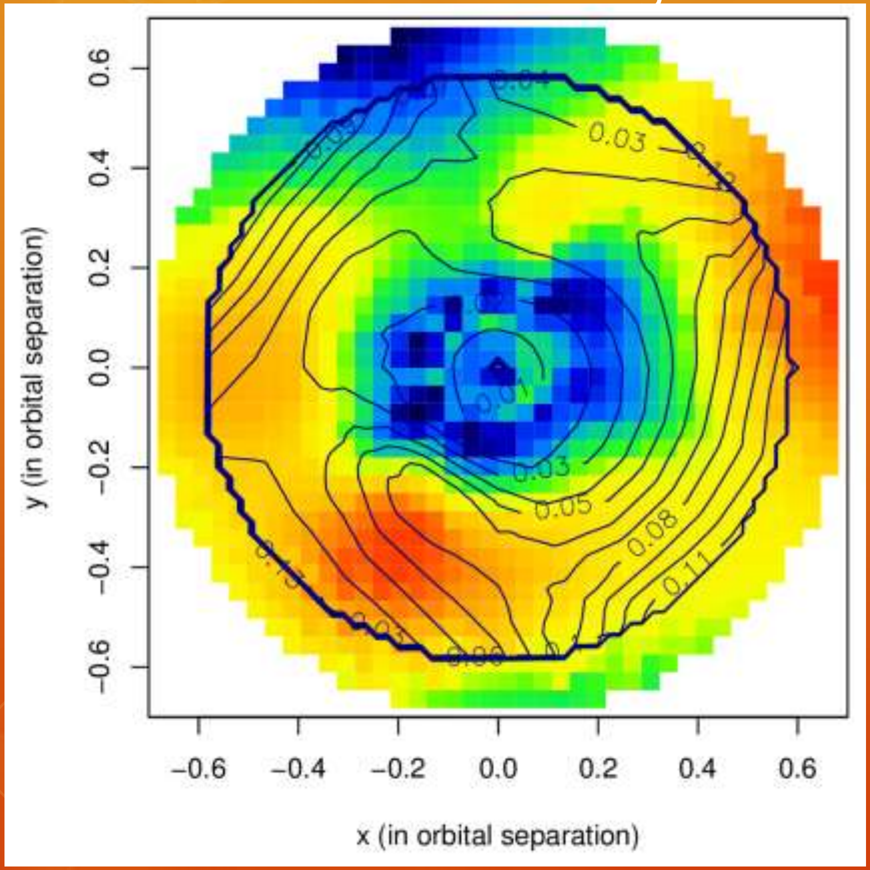




- SN 2009dc (Type Ia)
  - Yamanaka et al. (2009)
  - Mv = -19.90 →most luminous class → Ni mass 1.2 +/- 0.3 M_sun
  - The progenitor WD probably had super-Chandrasekhar mass
- Quick start of follow-up observations

Dwarf nova accretion disk

Color: emission line intensity
Contour: disk height



Accretion disk physics in outburst

- Line forming region : Doppler tomography using time-series spectra
- Disk height : Reconstruction using time-series photometric data (Uemura+13)

Compression → high pressure → line formation? → expansion

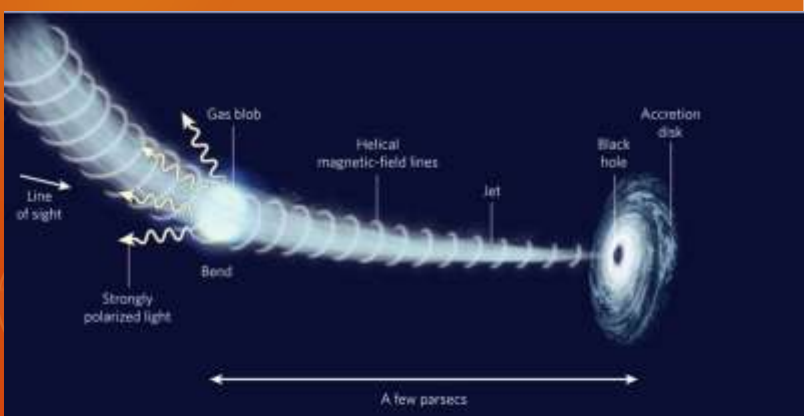
Data

- Simultaneous time-series photometry & spectroscopy covering a few orbital periods (> a half night).

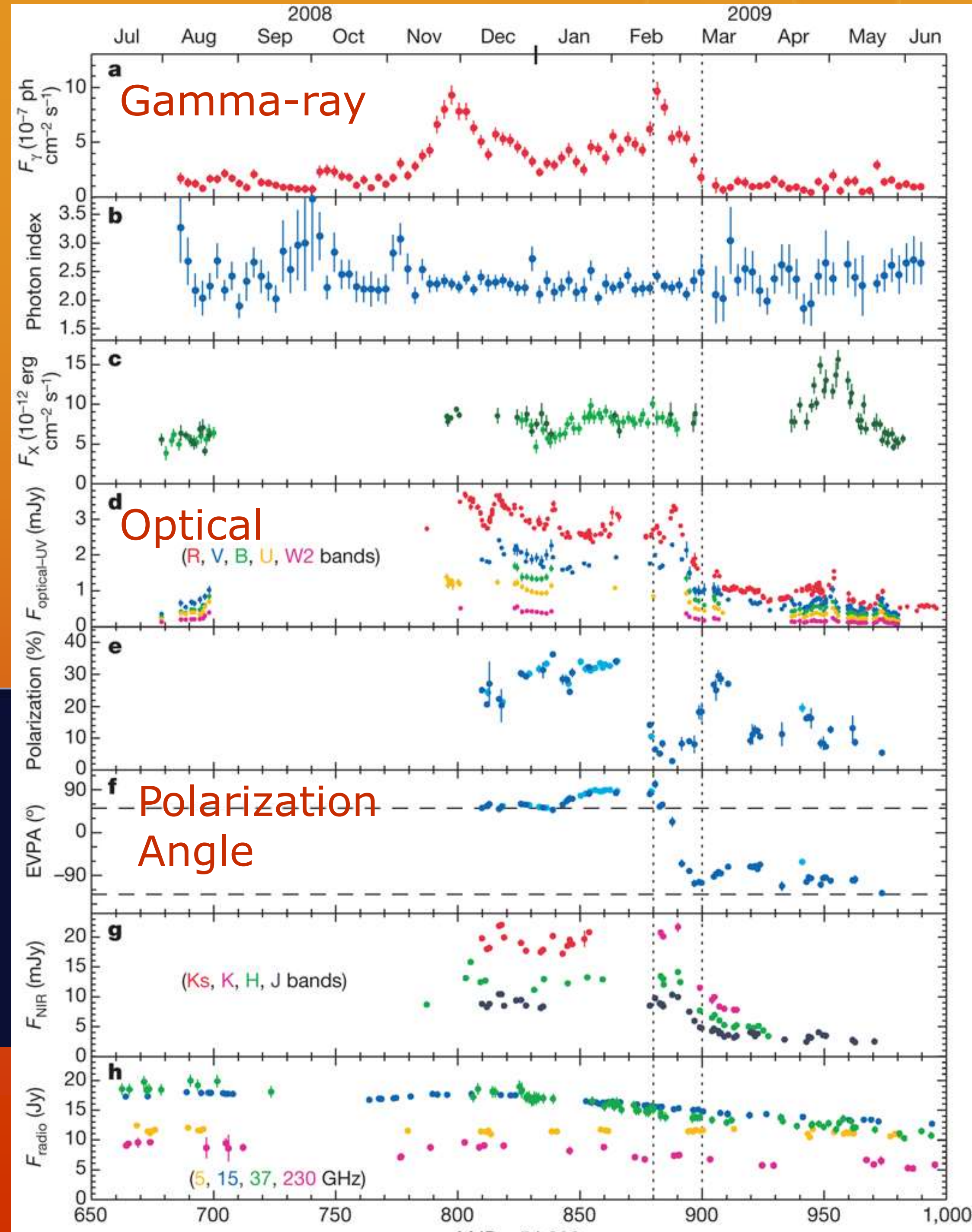
- Flexible operation

Blazar polarization

- Abdo+10, Nature, 463, 919
- Position angle rotation in 3C 279
- Polarization rotated with the decay from a gamma-ray flare



- Multi-wavelength collaboration



For effective operations of small-medium size telescopes

- Unique telescope/instruments
  - For special projects
- Survey
  - Plenty of observation time
- Data analysis, Modeling technique

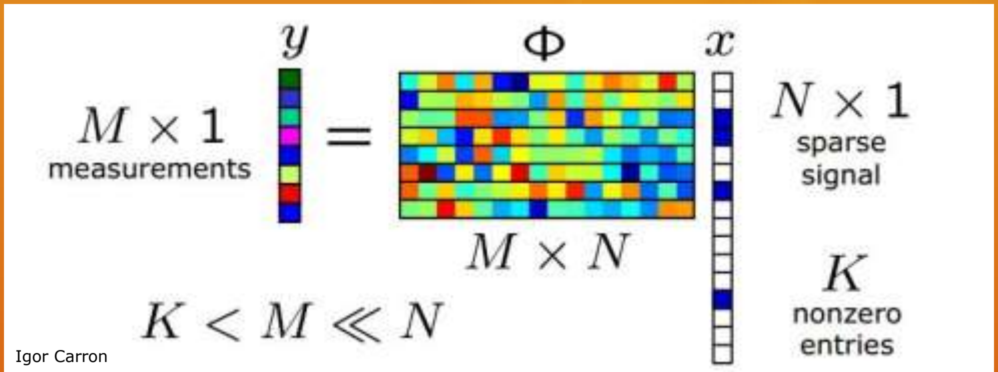
Compressed Sensing (CS)

$$\boldsymbol{y} = A\boldsymbol{x}$$

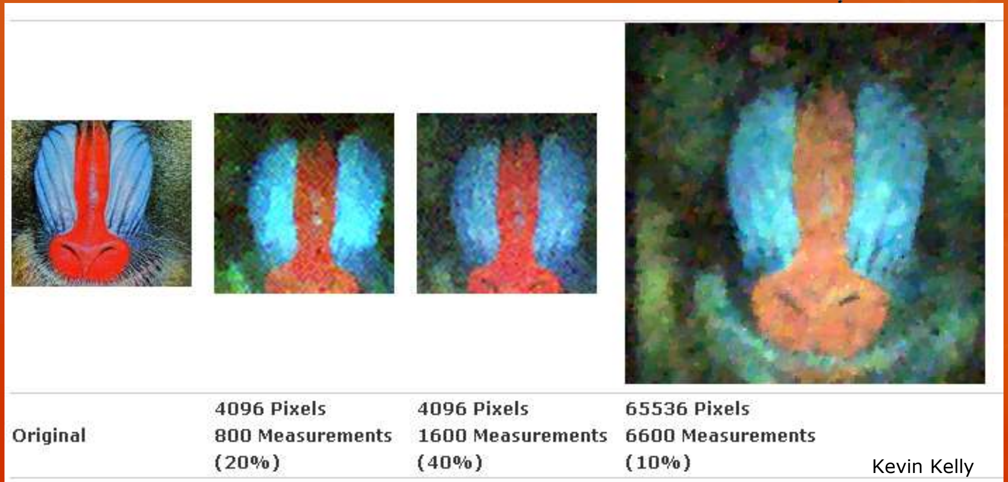
$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix}$$

data model

- m<n: ill-posed problem
- L1 norm minimization (reconstruction of a sparse *x*)
- sparsity



$$\hat{x} = \operatorname{argmin} \|\boldsymbol{y} - A\boldsymbol{x}\|_2^2 + \lambda \sum |x_i|$$



Period analysis with CS

$$\boldsymbol{y} = \mathcal{F}^{-1}\boldsymbol{x}$$

time domain

Frequency domain

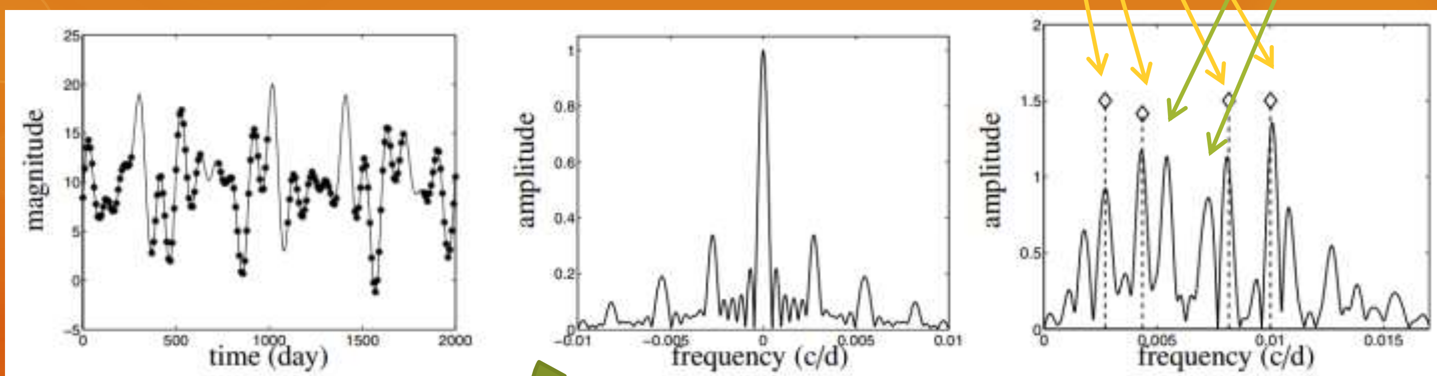
True signals

False signals

Light curve
(unevenly sampled)

Window function

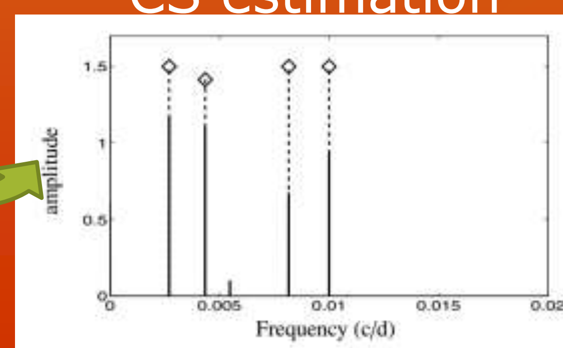
Standard power spectrum



Bourguignon et al. (2007)
Kato & Uemura (2013)

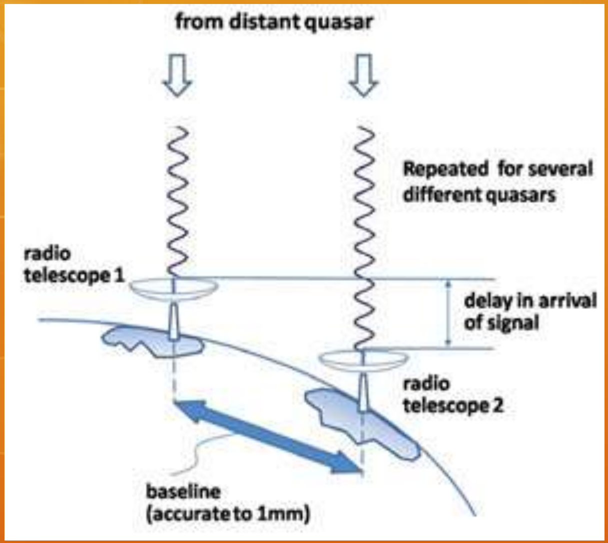
CS estimation

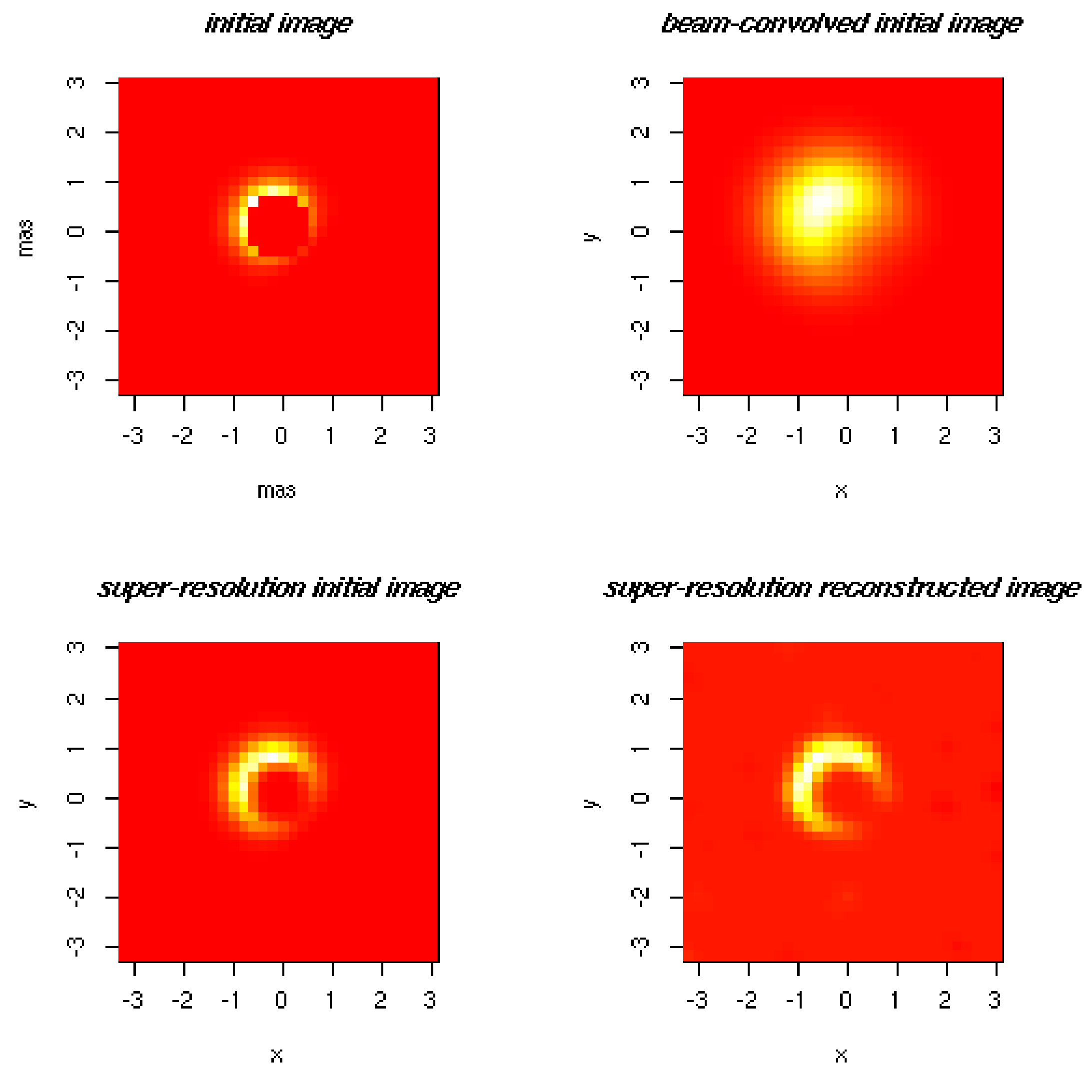
$$\mathrm{argmin}\ \|\boldsymbol{y} - \mathcal{F}^{-1}\boldsymbol{x}\|_2^2 + \lambda\|\boldsymbol{x}\|_1$$



- Sparse in the frequent domain

Radio interferometer (VLBI)

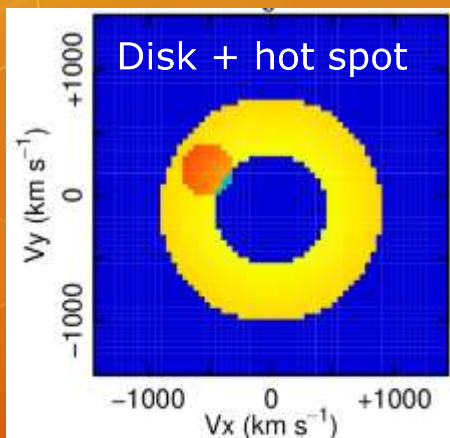




- Observation = 2D Fourier transform of radio maps
- Resolving a black hole shadow (Honma, et al. 2012)
- Sparse in spatial domain

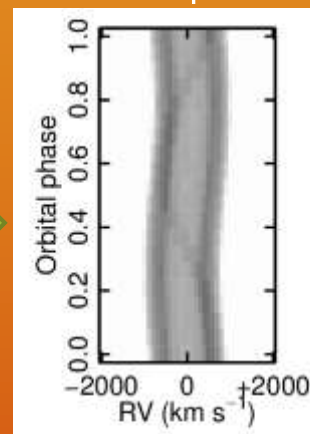
Doppler tomography

Line intensity in the velocity spase



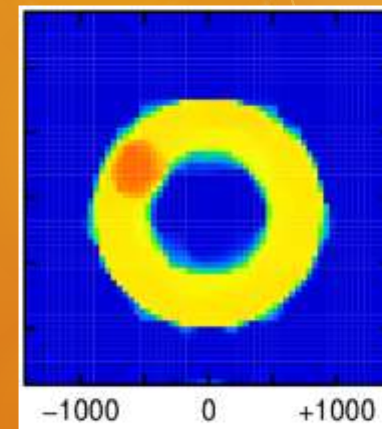
Obs.

Trailed spectra

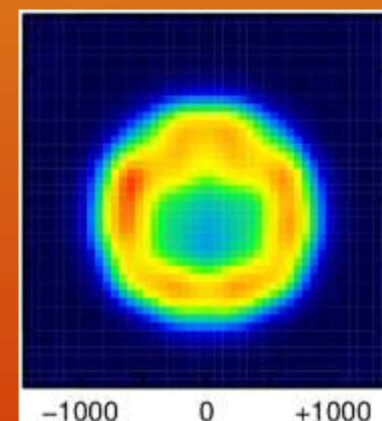


Reconstr.

TVM reconstruction



MEM reconstruction



$$\mathrm{argmin}\ \|\boldsymbol{y}-\mathcal{F}^{-1}\boldsymbol{x}\|_2^2+\lambda\sum_{i,j}|x_{i+1,j}-x_{i,j}|+|x_{i,j+1}-x_{i,j}|$$

- Reconstruction of the emission line map from line-profile variations
- Instead of the standard MEM, we use the Total Variation Minimization (TVM; sparse in the gradient domain)

Summary

- The "Kanata" project
  - Generalist telescope for astronomical transients
    - Unique instrument
    - Quick follow-up observation
    - Flexible operation
- Importance of advanced technique for modeling.